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SOIL FERTILITY & PLANT NUTRITION

Soil Nitrogen and Phosphorus Availability for Field-Applied Slurry from Swine Fed Traditional and Low-Phytate Corn

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Swine (*Sus scrofa*) slurry contains nutrients essential for crop production but usually contains more P relative to N than is required by most crops, creating the potential for negative environmental impacts. Diet modifications such as low-phytate corn (*Zea mays* L.) have resulted in improved bioavailability of P and reduced manure P content. A field study was conducted to compare in situ availability of N and P at two sites. One site received three annual additions of manure from swine fed low-phytate corn or traditional corn diets or inorganic fertilizer, surface applied to rainfed no-till sorghum [*Sorghum bicolor* (L.) Moench]. A second site received a one-time application and incorporation of the same nutrient treatments to irrigated corn. Nutrient treatments were applied at rates intended to meet crop N needs. At both sites, an in situ soil core resin bag technique was used to determine available N and P during the growing season. Potentially mineralizable N was 70% of applied N and extractable P was 100% of applied P for manure from both diets. Incorporation of swine slurry reduced potentially mineralizable N to 40% the year of application and 30% the year after application and reduced extractable P to 60% the year of application and 40% the year after application for both diets. Modified diets reduced the P content of the manure but not the availability of N or P.

Abbreviations: LPC, low-phytate corn; TC, traditional corn.

Swine production is estimated to generate >1.1 Tg of N and 0.6 Tg of P annually in the United States (Gollehon et al., 2001). Swine slurry can serve as a source of plant nutrients in crop production systems but when applied in excessive amounts, the potential exists for environmental contamination (Sims et al., 1998). Land application of manure to meet the N needs of a crop typically leads to accumulation of P in the surface soil layer (Eghball and Power, 1999; Ferguson et al., 2005). Accumulation of P results because swine slurry typically contains more P relative to N than is needed by most crops. Swine are monogastric animals and lack the ability to efficiently utilize P as it is stored in most feed grains. To meet animal needs, swine feed is typically supplemented with additional inorganic P. Poor utilization of grain P and supplementation to meet animal needs results in a relatively large amount of P being excreted by swine.

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Efforts to reduce the P content in swine slurry include improving the bioavailability of P in feed grains by adding the enzyme phytase to the diet or feeding grain that stores P in a more available form. Low-phytate corn (LPC) contains a mutant gene that results in grain containing similar amounts of total P as traditional corn (TC) but a greater proportion of that P as phosphate rather than phytate (Ertl et al., 1998). The bioavailability of P in monogastric animals is greater when LPC is used as a feed source compared with a TC feed source (Spencer et al., 2000; Sands et al., 2001). Use of the enzyme phytase in a TC diet has a similar result (Sands et al., 2001). Manure from monogastric animals fed a LPC diet has a N/P ratio (4.5:1) closer to that needed by a corn crop (6:1) than does manure from animals fed a TC diet (3.3:1) (Wienhold and Miller, 2004). The higher N/P ratio results in slower accumulation of P in soil when swine slurry is applied at crop N rates (Wienhold, 2005).

As alterations in feed reduce the P content of manure, studies are needed to determine if the plant availability of the P remaining in the manure is affected. The distribution of P in extracts from a sequential extraction procedure was similar between manure from swine fed a TC diet or a LPC diet (Wienhold and Miller, 2004). Leytem et al. (2004) determined that phosphate was the major form of P in manure from swine fed either wild-type or low-phytate barley (*Hordeum vulgare* L.) and concluded that phytate was hydrolyzed by hindgut microflora before excretion. These results suggest that the availability of P in manure from swine fed LPC diets should be similar to that in manure from swine fed TC diets. Gollany et al. (2003) conducted a laboratory study that compared extractable P in a sandy loam and a silt loam receiving inorganic fertilizer P or slurry from swine fed either LPC or TC diets and found that

P availability for both slurries was similar and was 60% that of inorganic fertilizer P.

We know of no studies that have compared nutrient availability in manure from swine fed altered diets under field conditions. The objective of this study was to compare N and P availability based on KCl-extractable N and soil test P in soils receiving manure from swine fed a LPC diet, manure from swine fed a TC diet, or inorganic fertilizer.

MATERIALS AND METHODS

In situ availability of N and P was determined at two locations, the Rogers Memorial Research Farm near Lincoln, NE, and the University of Nebraska South Central Research and Extension Center near Clay Center, NE. The study at the Rogers Farm compared N and P availability among nutrient treatments applied in three consecutive years. The study at Clay Center compared N and P availability among nutrient treatments in the year of application and in the year following application. Nutrient treatments for both studies included a control (no nutrients added), inorganic fertilizer (N as NH_4NO_3 and P as superphosphate), manure from swine fed a LPC diet, and manure from swine fed a TC diet. Inorganic fertilizer was applied at recommended rates based on average yields at each site with no adjustment for residual soil inorganic N or extractable P. Both manures were added at rates intended to meet the N needs of the crop, assuming that 70% of the N in the manure was available to the crop during the growing season (Koelsch and Shapiro, 1997). The two manures differed in nutrient concentrations and this difference resulted in year-to-year differences in N and P application rates (Wienhold and Miller, 2004).

To generate the two different manure sources, corn exhibiting the low-phytate trait (Pioneer X1127PP) and the same cultivar without the low-phytate trait (Pioneer Alicia) were grown under irrigation near Shelton, NE, in 1998. Recommended practices for irrigation, fertilizer application, and pest control were used to optimize yield. The stands were harvested and stored separately until use as feed. The two corn sources were used to prepare feed appropriate for a starter phase swine diet in the spring of 1999, 2000, and 2001. Each year the two diets were fed to swine in elevated pens with 10 pigs per pen. Each diet was fed to all pigs in six randomly assigned pens. Trays were placed under each pen and slurry (manure and urine) was collected. Slurry from swine fed each of the two diets was stored separately (<30 d) until needed for field application. Slurry was sampled at two times for nutrient content, once during slurry collection at the feeding facility and a second during field application of the slurry (14–30 d later). Slurry samples were sent to a commercial laboratory for nutrient analysis. Results from the first nutrient analysis were used to calculate application rates. Results from the second nutrient analysis were used to account for changes in slurry nutrient concentration during storage and to calculate actual nutrient amounts applied (Table 1). Slurry from swine fed a TC diet had a lower dry matter content (3.6 vs. 7.2%) and N/P ratio (3.3:1 vs. 4.5:1) than slurry from swine fed a LPC diet (Wienhold and Miller, 2004).

Rogers Farm

Soil at the Rogers Farm was an Aksarben (formerly Sharpsburg) silty clay loam (fine, smectitic, mesic Typic Argiudoll) with a total N concentration of 1.0 g kg^{-1}, an organic C concentration of 10.2 g kg^{-1}, Bray P concentration of 7.8 mg kg^{-1}, bulk density of 1.36 g cm^{-3}, and pH of 5.7 in the 0- to 15-cm depth. The field had been cropped in a rainfed no-till grain sorghum–soybean [*Glycine max* (L.) Merr.]–winter wheat (*Triticum aestivum* L.) rotation for several years and was planted to sorghum the year before this study. Plots received the same treatment and in situ nutrient availability was determined each year. Treatments were applied in 1999, 2000, and 2001 to 3.6- by 9.7-m plots arranged in a completely randomized design with three replications. Sorghum was direct seeded into the previous years' residue in mid-May each year and treatments were surface applied at crop emergence.

Precipitation from 1 May through 31 October totaled 47.4 cm in 1999, 39.3 cm in 2000, and 37.0 cm in 2001, compared with the 20-yr average of 44.6 cm. Accumulated growing degree days (base 10°C) from 1 May to 31 October were 1842°C in 1999, 1973°C in 2000, and 1853°C in 2001, compared with a 20-yr average of 1730°C.

Clay Center

Soil at the Clay Center site was a well-drained Hastings silt loam (fine, smectitic, mesic Udic Argiustoll) with a field average total N concentration of 0.8 g kg^{-1}, organic C concentration of 17 g kg^{-1}, Bray P concentration of 7.7 mg kg^{-1}, bulk density of 1.41 g cm^{-3}, and pH of 6.7 in the 0- to 15-cm depth. The field had been in a conventionally tilled (fall disk tillage to incorporate crop residue, spring tillage with a field cultivator, and in-row cultivation to control weeds following germination) irrigated soybean–corn rotation. The field was planted to corn the year before this study. Plots received a nutrient treatment and in situ nutrient availability was determined during the year of application and the year after application. Treatments were applied at Site 1 in 1999 to 5- by 7-m plots arranged in a randomized block design with five replications. Nutrient treatments were applied, incorporated with a field cultivator, and corn was planted. In 2000, plots at Site 1 were tilled and corn was planted with no additional nutrient application. In 2000, treatments were also applied to an adjacent set of 5- by 7-m plots (Site 2) arranged in a randomized block

Table 1. Swine slurry, total N, and total P application rates for manure from swine fed traditional corn (TC) or low-phytate corn (LPC) or from inorganic fertilizer (IF) at the Rogers Memorial Farm and Clay Center study sites.

Nutrient	Application rate			
	TC	LPC	IF	Control
		Rogers Farm, 1999		
Slurry, Mg ha^{-1}	25.5	25.5	–	–
N, kg ha^{-1}	112	88	123	0
P, kg ha^{-1}	43	30	30	0
		Rogers Farm, 2000		
Slurry, Mg ha^{-1}	35.1	20.7	–	–
N, kg ha^{-1}	258	194	123	0
P, kg ha^{-1}	57	34	30	0
		Rogers Farm, 2001		
Slurry, Mg ha^{-1}	30.0	24.1		
N, kg ha^{-1}	120	121	123	0
P, kg ha^{-1}	40	31	30	0
		Clay Center, 1999		
Slurry, Mg ha^{-1}	42.7	42.7	–	–
N, kg ha^{-1}	178	123	179	0
P, kg ha^{-1}	68	42	50	0
		Clay Center, 2000		
Slurry, Mg ha^{-1}	50.8	46.4	–	–
N, kg ha^{-1}	175	271	179	0
P, kg ha^{-1}	54	58	50	0

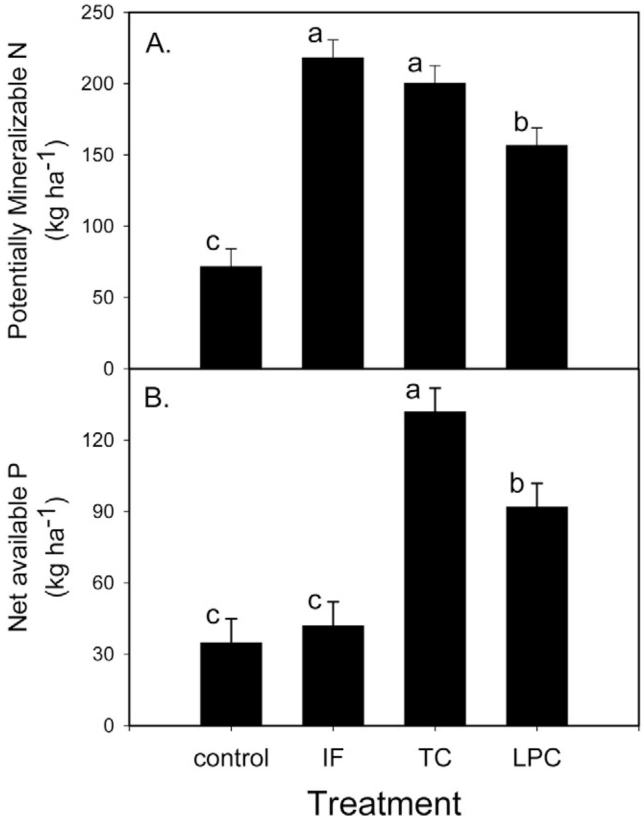

Fig. 1. Average growing-season (A) potentially mineralizable N and (B) net extractable P as a function of nutrient treatment (inorganic fertilizer [IF], traditional corn [TC], or low-phytate corn [LPC]) to no-till continuous sorghum at the Rogers Memorial Research Farm. Error bars represent one standard error of the mean. Bars within a figure having different letters above them are significantly different at *P* < 0.05.

design with five replications, incorporated, and corn was planted. In 2001, plots at Site 2 were tilled and corn planted with no additional nutrient application.

Precipitation from 1 May through 31 October totaled 42.2 cm in 1999, 36.8 cm in 2000, and 43.6 cm in 2001. Irrigation provided an additional 20.1 cm of water in 1999, 35.5 cm in 2000, and 41.5 cm in 2001. Accumulated growing degree days (base 10°C) from 1 May to 31 October were 1706°C in 1999, 1849°C in 2000, and 1769°C in 2001, compared with a 20-yr average of 1730°C.

In Situ Nutrient Availability

In situ nutrient availability was determined using the method similar to that described by Kolberg et al. (1997). Briefly, a 4.75-cm-diameter metal cylinder was inserted 17 cm into the soil and the cylinder containing an intact soil core was removed from the soil. Two centimeters of soil was removed from the bottom of the cylinder and a nylon bag containing 35 cm^3 of a 1:2 mixture of Na-saturated cation (C-249) and Cl-saturated anion (ASB-1P) resin (Sybron Chemical Inc., Birmingham, NJ) was inserted into the bottom of the cylinder to capture inorganic N and P leached through the soil column. The bottom of the core was then covered with heavy nylon cloth to prevent root entry and the cylinder was reinserted into the original hole. Cylinders were inserted between plants in the row the same day as slurry was applied at the Rogers Farm site and 1 wk after slurry application at the Clay Center site. Twenty cylinders were inserted in each plot on 14 June 1999, 8 May 2000, and 14 May 2001 at the Rogers Farm and on 7 June 1999, 30 May 2000, and 17 May 2001 at Clay Center. Initial inorganic N and extractable P content was determined in soil samples collected from the 0- to 15-cm depth when the cylinders were installed at both sites each year.

At the Rogers Farm, five cylinders from each plot were randomly selected for removal 28, 56, 85, and 114 d after installation in 1999; 37, 65, 93, and 133 d after installation in 2000; and 37, 65, 100, and 134 d after installation in 2001. At Clay Center, five cylinders from each plot were randomly selected for removal 29, 56, 85, and 99 d after installation in 1999; 28, 56, 84, and 112 d after installation in 2000; and 35, 63, 98, and 133 d after installation in 2001. Resin from the five cylinders was combined and stored at 4°C (<30 d) until analysis for inorganic N and P. Soil was removed from the five cylinders, composited, air dried, and ground to pass a 2-mm sieve. Inorganic N in the soil was determined by 2 mol L^{-1} KCl extraction (Keeney, 1982). Inorganic N in the resin was extracted by five 15-min serial extractions with 2 mol L^{-1} KCl (Kolberg et al., 1997). Inorganic N (NH_4 and NO_3) was determined in all extracts colorimetrically using a Lachat flow injection ion analyzer (Zellweger Analytics, Lachat Instruments Div., Milwaukee, WI). Extractable P in the soil was determined by soil extraction using the method of Bray and Kurtz (1945). Phosphorus adsorbed to the resin was extracted using five 15-min serial extractions with 0.5 mol L^{-1} HCl (Sibbeson, 1977). The concentration of P in the extracts was determined spectrophotometrically at 882 nm using the phosphomolybdate blue method (Murphy and Riley, 1962).

Net mineralized N or extractable P was calculated by summing inorganic N and P from soil and resin and subtracting inorganic N and P present in the soil when the cylinders were installed. Cumulative inorganic N and P was converted to a volumetric basis using measured bulk densities for the 0- to 15-cm depth at each site. Potentially mineralizable N and first-order rate constants were calculated by fitting cumulative N as a function of time using nonlinear regression (Smith et al., 1980).

Analysis of variance was used to determine differences in potentially mineralizable N or net extractable P and among rate constants for N mineralization (SAS Institute, 1985). At the Rogers Farm, the experimental design was completely random, with repeated measures across years. At Clay Center, the experimental design was randomized blocks with two sites (the first site consisting of treatments applied in 1999 and the adjacent second site consisting of treatments applied in 2000), with repeated measures across years at each site. Differences were declared significant at the 0.05 probability level. Differences among means were determined by pairwise comparisons made with the DIFF option of the LSMEANS statement. The Tukey adjustment option of the LSMEANS statement was used to protect the experimentwise error rate.

RESULTS AND DISCUSSION

Rogers Farm

There was no interaction between treatments and years for mineralizable N. Nutrient treatment affected potentially mineralizable N ($P < 0.0001$), with mineralizable N being higher in the inorganic fertilizer and manure from swine fed a TC diet treatments than in the manure from swine fed a LPC diet treatment, with all nutrient treatments being higher than the control (Fig. 1A). Subtracting mineralizable N in the control from that in the two manure treatments and expressing the remainder as a percentage of total N applied results in 70% of the applied N in the TC diet treatments and 63% of applied N in the LPC diet treatments being available when averaged across years. These values are close to the 70% recommended by Koelsch and Shapiro (1997) but lower than the 90% reported by Eghball et al. (2002). Mineralizable N also differed among years (P = 0.037), being higher in 1999 (162.2 ± 11.1 kg ha^{-1}) and 2001 (179.4 ± 14.9 kg ha^{-1}) than in 2000 (143.4 ± 6.3 kg ha^{-1}). Lower mineralizable N in 2000 may be due to hotter, drier conditions during that year than the other 2 yr. Soil in the mineralization tubes dried out during several periods in 2000 and this probably reduced mineralization (Cassman and Munns, 1980).

Table 2. First-order N mineralization rate constants (*k*) as a function of time and nutrient source treatment for the Rogers Memorial Research Farm site.

Treatment†	1999	2000	2001	Avg.
	d^{-1}			
Control	0.042 ± 0.027 aA‡	0.014 ± 0.013 aA	0.018 ± 0.010 aB	0.025 ± 0.010 A
IF	0.073 ± 0.027 aA	0.052 ± 0.013 aA	0.039 ± 0.010 aB	0.055 ± 0.010 A
TC	0.013 ± 0.027 bA	0.027 ± 0.013 bA	0.093 ± 0.010 aA	0.044 ± 0.010 A
LPC	0.033 ± 0.027 bA	0.032 ± 0.013 bA	0.089 ± 0.010 aA	0.051 ± 0.010 A
Avg.	0.040 ± 0.013 ab	0.031 ± 0.007 b	0.060 ± 0.005 a	

† Control, no nutrients added; IF, inorganic fertilizer; TC, nutrients added as manure from swine fed a traditional corn diet; LPC, nutrients added as manure from swine fed a low-phytate corn diet.

‡ Mean ± SE; means within a row followed by different lowercase letters are different at $P < 0.05$; means within a column followed by different uppercase letters are different at $P < 0.05$.

There was an interaction between treatments and years (P = 0.008) for the N mineralization rate (Table 2). The N mineralization rate was similar across years in the control and inorganic fertilizer treatments, while the N mineralization rate was greater in the two manure treatments in 2001 than in 1999 or 2000. The rate constants for N mineralization in this study are similar to those reported by Eghball (2000) for beef feedlot manure applied to a Sharpsburg soil.

Within a treatment, extractable P was similar among years and there was no interaction between treatments and years. Net extractable P did not change across sampling times within a year, suggesting little immobilization or mineralization of organic P (data not shown). Gollany et al. (2003) reported similar extractable P levels across six sampling times during a 100-d incubation for manure from swine fed LPC and TC diets in a silt loam soil. In our study, essentially all of the extractable P was extracted from the soil and only trace amounts of P were extracted from the resin. Net extractable P differed among treatments (P = 0.0004). Extractable P was lower in the control and inorganic fertilizer treatments than in the manure treatments, and extractable P was greater from TC swine manure than LPC swine manure (Fig. 1B). Lower extractable P in the inorganic fertilizer treatment may have been due to immobilization when applied to a no-till soil surface. A higher extractable P in slurry-treated soils may be due to slightly higher application rates and enhanced mineralization when surface applied. In a laboratory study using a soil similar to that at the Rogers Farm, Eghball et al. (2005) reported immobilization of inorganic fertilizer P and higher extractable P in slurry-treated soil. Higher extractable P in the TC manure treatment is due to a higher application rate of P in that treatment (Table 1). The TC manure contained more P relative to N than did the LPC manure, resulting in higher P application when manure was applied at crop N rates (Wienhold and Miller, 2004). For soils with adequate P levels, Eghball et al. (2002) suggested that manure P be considered 100% available. Results at this location support that suggestion, with extractable P accounting for 94% of the applied P in the TC manure treatment and 97% of the applied P in the LPC manure treatment.

Clay Center

Potentially mineralizable N differed among treatments (P = 0.03), being lower in the control treatment than in the inorganic fertilizer and LPC swine manure treatments (Fig. 2A). Potentially mineralizable N in the TC swine manure treatment was similar to that in the inorganic fertilizer and LPC swine manure treatments but did not differ from the control. Potentially mineralizable N in the two manure treatments expressed as a percentage of N applied results in ~40% of the applied N being available in those two treatments. The percentage of applied N in slurry that was available is lower than the 70% suggested by Koelsch and Shapiro (1997). A number of factors could potentially explain the lower availability of applied N at Clay Center than at the Rogers Farm. Tillage used

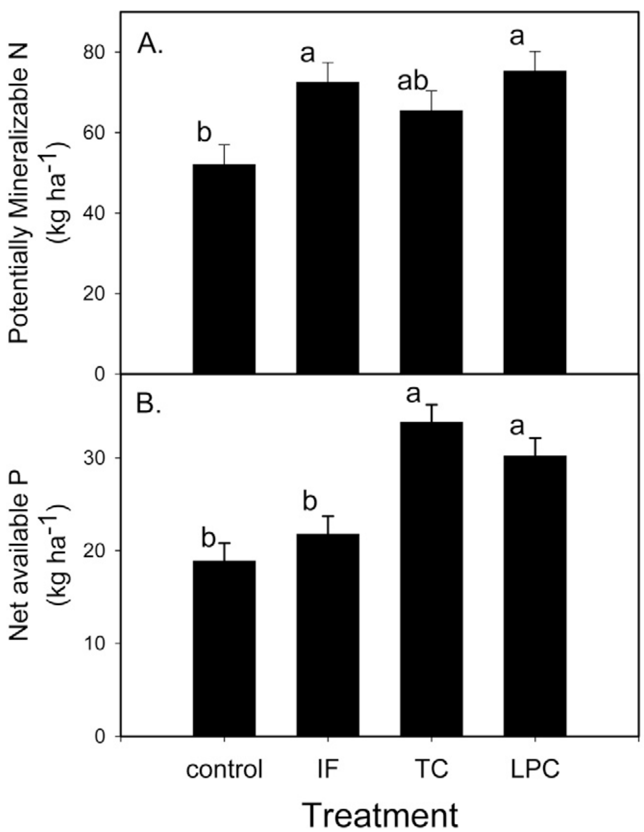

Fig. 2. Average growing-season (A) potentially mineralizable N and (B) net extractable P as a function of nutrient treatment (inorganic fertilizer [IF], traditional corn [TC], or low-phytate corn [LPC]) to conventionally tilled continuous corn at the Clay Center site. Error bars represent one standard error of the mean. Bars within a figure having different letters above them are significantly different at *P* < 0.05.

Table 3. First-order N mineralization rate constants (k) as a function of time since application and site for the Clay Center research site.

Site	Year of application	Year after application	Avg.
	d^{-1}		
1	0.037 ± 0.006 aA†	0.028 ± 0.003 aA	0.033 ± 0.002 A
2	0.017 ± 0.002 bB	0.034 ± 0.002 aA	0.025 ± 0.001 B
Avg.	0.027 ± 0.003 a	0.031 ± 0.002 a	

† Mean ± SE; for each group of rate constants means within a row followed by different lowercase letters are different at $P < 0.05$; means within a column followed by different uppercase letters are different at $P < 0.05$.

to incorporate the slurry may have placed some of the slurry below the 17-cm depth sampled by the mineralization tubes. Incorporation of the slurry with the abundant low-N residue from the previous crop may have resulted in immobilization of slurry N during the stover decomposition process. In addition, soils at the two sites may differ in their mineralization potential, and higher amounts of crop residue produced under irrigation at the Clay Center site may have immobilized more N compared with the Rogers Farm site.

There were no interactions between treatment, year, and site for potentially mineralizable N. Potentially mineralizable N differed among years ($P = 0.003$) and was greater in the year of application (78.4 ± 5.2 kg ha^{-1}) than in the year following application (54.3 ± 1.5 kg ha^{-1}). Lower N availability in years following application of manure has been observed by others (Eghball and Power, 1999). Pratt et al. (1973) developed a decay series for N availability in years following application, with 75% available the year of application and <10% available the second and third years after application. Our results suggest that about 45% of N applied in swine slurry is available the year of application and 30% the year following application. Availability of N during the year of application is lower and availability during the year after application is higher than previous reports, which is probably due to immobilization in decomposing residue during the first year and mineralization during the second year. Potentially mineralizable N also differed among sites ($P < 0.01$), being greater at Site 2 (74.9 ± 4.5 kg ha^{-1}) than at Site 1 (57.8 ± 2.5 kg ha^{-1}). Greater N mineralization at Site 2 may be due to higher accumulated growing degree days during the year of application than during the year of application at Site 1. Mineralization increases with increasing temperature as long as soil moisture is adequate (Cassman and Munns, 1980).

There was an interaction between site and year ($P = 0.03$) for the N mineralization rate. At Site 1, the rate constant in the year of application was similar to the rate constant the year after application, while at Site 2, the rate constant in the year of application was less than the rate constant the year after application (Table 3). During the year of application, the rate constant was greater at Site 1 than at Site 2, while during the year after application, the rate constant was similar between the two sites. There were no differences in N mineralization rate among the nutrient treatments and there were no interactions involving nutrient treatment, site, and year.

Net extractable P was similar between the two sites and there were no interactions among site, year, and treatment. Net extractable P did not change across sampling times, suggesting little immobilization or mineralization of organic P. In our study, essentially all of the extractable P was extracted from the soil and only trace amounts of P were extracted from the resin. Net extractable P differed between years ($P = 0.008$) and was greater in the year of application (28.6 ± 1.6 kg ha^{-1}) than in the year after application (23.8 ± 0.7 kg ha^{-1}). The lower availability in the year after application was probably due to crop uptake the previous year or immobilization of P. Net extractable P differed among the nutrient treatments ($P = 0.0006$) and was greater in the two manure treatments (55% of that applied in the TC manure treatment and 30% of that applied in the LPC manure treatment) than in the control or inorganic fertilizer treatments (22% of that applied) (Fig. 2B). Eghball et al. (2005) also reported higher availability of P in soils receiving slurry than in soils receiving inorganic fertilizer P.

Management Implications

Previous research on P fractionation in LPC manure (Wienhold and Miller, 2004) and laboratory studies on P availability from LPC manure amended soils (Gollany et al., 2003) have concluded that the use of LPC in swine feed results in manure with a lower P content relative to N with no difference in solubility, crop availability, or lability of the P when compared with TC manure. Leytem et al. (2004) utilized ^{31}P nuclear magnetic resonance spectroscopy to characterize P fractions in manure from swine fed either wild-type barley (*Hordeum vulgare* L.) or several low-phytate cultivars and concluded that phytate P is hydrolyzed by hindgut microflora, resulting in phosphate being the dominant form of excreted P. The present field study confirms that P in manure from both feed types is readily available and that P nutrient application recommendations developed for TC manure should be applicable to LPC manure as well.

Land application of manure at rates to meet the N needs of the crop typically leads to accumulation of P in the surface layer. Manure from swine fed the LPC diet had a N/P ratio (4.5:1) closer to that needed by a corn crop (6:1) than did the manure from animals fed a TC diet (3.3:1) (Wienhold and Miller, 2004). The higher N/P ratio in manure from swine fed LPC diets results in slower accumulation of soil P when manure is applied at N rates (Wienhold, 2005). The present study demonstrates that even though less P is applied relative to N when manure from swine fed LPC diets is used, the availability of that P should be sufficient to meet crop needs. Application at crop N rates will result in slower accumulation of soil P when manure from swine fed LPC diets is used (Wienhold, 2005). Alternatively, application at crop P rates of manure from swine fed LPC diets will require less additional inorganic N to meet crop N needs than if manure from swine fed TC diets is used.

Manure is usually incorporated after application to reduce odor and minimize volatilization losses of N. Stevenson et al. (1998) compared NH_3 volatilization losses from fresh beef manure surface applied to no-till plots to that incorporated in conventionally tilled plots and found that while losses were greater with surface application, the loss was <6% of N applied. They also reported that yield responses to manure were similar for surface application in no-till and incorporation in conventional tillage. While NH_3 volatilization was not measured in the present study, the high availability of N in manured plots at the Rogers Farm indicates that losses were not large.

Manure from swine fed LPC diets contains N and P that has high availability when surface applied or incorporated. When surface applied, potentially mineralizable N was 70% of applied N and extractable P was 100% of applied P for manure from both diets. Incorporation of swine slurry reduced potentially mineralizable N to 40% the year of application and 30% the year after application and reduced extractable P to 60% the year of application and 40% the year after application for both diets. Our results suggest that manure from swine fed LPC diets can be used as a fertilizer source using nutrient application recommendations developed for manure from TC diets. The use of LPC in swine diets has the potential for reducing P accumulation in surface soils while maintaining high availability of nutrients for crop production.

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